$^{74}$Ge: Pygmy Resonance and Low-Energy Enhancement

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Outline

i. $^{74}$Ge campaign - Motivation.

ii. Review of experimental approach to study the region of high-level density.

iii. $^{74}$Ge(p,p$'$) preliminary results.

iv. $^{74}$Ge(α,α$'$) close to final results.

v. Conclusion.
Motivation

Application: Impact of astrophysical environments on reaction rates?

Physics: Many open questions need to be answered:
- Is the shape of statistical spectra reaction dependent?
- Do different experimental methods yield the same result?
- What is the origin of the low-energy enhancement?
- Is the Brink Hypothesis valid?

Goal: To tackle these questions study $^{74}$Ge nucleus in a series of measurements
- Use different beams on $^{74}$Ge to populate states ($p$, $^4$He, $^3$He, gamma)

Combining these results following individual analyses will be very interesting and educational.
$^{74}$Ge Measurements

- PSF to individual discrete states in two different reactions using $^p$ and $^4$He beams

- 112 hours beam time
- 4 Silicon annular particle detectors with a total of 128 channels and 6 high-purity Germanium detectors with a total of 24 channels.
- populated in the reaction $^{74}$Ge($^p$,$^p'$) with 18 MeV.
- Analysis by B.V. Kheswa at iThemba LABS in South Africa.

- Beam time of 218 hours
- 2 Silicon W1 particle detectors with 64 channels and 9 Clover detectors.
- populate $^{74}$Ge nuclei in the reaction $^{74}$Ge($^4$He,$^4$He') 47 MeV
- Analysis by D. Negi (post-doc) at iThemba LABS in South Africa
Extracting information

Exploiting this equation and assuming dipole transitions dominate:

\[ f(E_\gamma) = f_{J^\pi}(E_\gamma) = \frac{\Gamma_{J^\pi}(E_i, E_\gamma) \rho_{J^\pi}(E_i)}{E_\gamma^{2\lambda+1}} \]

\[ N_{L_j}(E_i) \propto \sum_{J^\pi} \sigma_{J^\pi}(E_i) \Gamma_{J^\pi}(E_i, E_i - E_{L_j}) \rho_{J^\pi}(E_i) \]

\[ = f_{J^\pi}(E_i - E_{L_j}) E_\gamma^3 \sum_{J^\pi} \sigma_{J^\pi}(E_i) \]

\[ R = \frac{f(E_i - E_{L_1})}{f(E_i - E_{L_2})} = \frac{N_{L_1}(E_i)(E_i - E_{L_2})^3}{N_{L_2}(E_i)(E_i - E_{L_1})^3} \]

One step transitions to ground state are also of interest.
• (d,p) reactions to populate $^{95}$Mo.
• 24 ratios in total.
• Independent of level density.
• Independent of (d,p) cross-section.
• No systematic uncertainties.

Blue: $^{94}$Mo(d,p) data

Blue: $^{94}\text{Mo}(d,p)$ data

$\chi^2$ method
$^{74}\text{Ge}(p,p')$: Ratio Method

Extracted quasi-continuum feeding to 7 states (red). Other good candidates are shown in black.

\[ N_{L_j}(E_i) \propto \sum_{J^\pi} \sigma_{J^\pi}(E_i) \Gamma_{J^\pi}(E_i, E_i - E_{L_j}) \rho_{J^\pi}(E_i) \]

\[ = f_{J^\pi}(E_i - E_{L_j}) E_i^3 \sum_{J^\pi} \sigma_{J^\pi}(E_i) \]

\[ R = \frac{f(E_i - E_{L_1})}{f(E_i - E_{L_2})} = \frac{N_{L_1}(E_i)(E_i - E_{L_2})^3}{N_{L_2}(E_i)(E_i - E_{L_1})^3} \]
$^{74}$Ge(p,p$'$): Ratio Method

Extracted quasi-continuum feeding to 7 states (red). Other good candidates are shown in black.

$$N_{L_j}(E_i) \propto \sum_{j_{\text{sat}}} \sigma_{j_{\text{sat}}}(E_i) \Gamma_{j_{\text{sat}}}(E_i, E_i - E_{L_j}) \rho_{j_{\text{sat}}}(E_i)$$

$$= f_{j_{\text{sat}}}(E_i - E_{L_j}) E_i^3 \sum_{j_{\text{sat}}} \sigma_{j_{\text{sat}}}(E_i)$$

$$R = \frac{f(E_i - E_{L1})}{f(E_i - E_{L2})} = \frac{N_{L_1}(E_i)(E_i - E_{L2})^3}{N_{L_2}(E_i)(E_i - E_{L1})^3}$$

Thanks to B.V. Kheswa

We do observe the low-energy enhancement!
$^{74}$Ge(α,α') \( \text{: Ratio Method} \)

Extracted quasi-continuum feeding to 2 states (red).

\[
N_{L_j}(E_i) \propto \sum_{J^\pi} \sigma_{J^\pi}(E_i) \Gamma_{J^\pi}(E_i, E_i - E_{L_j}) \rho_{J^\pi}(E_i)
= f_{J^\pi}(E_i - E_{L_j}) E_i^3 \sum_{J^\pi} \sigma_{J^\pi}(E_i)
\]

\[
R = \frac{f(E_i - E_{L_1})}{f(E_i - E_{L_2})} = \frac{N_{L_1}(E_i)(E_i - E_{L_2})^3}{N_{L_2}(E_i)(E_i - E_{L_1})^3}
\]

Very low statistics, large bins, large error bars.

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$^{74}\text{Ge}(\alpha,\alpha')$: Ratio Method

Extracted quasi-continuum feeding to 2 states (red). No other good candidates.

$$N_{L_j}(E_i) \propto \sum_{j} \sigma_{j^\pi}(E_i) \Gamma_{j^\pi}(E_i, E_i - E_{L_j}) \rho_{j^\pi}(E_i)$$

$$= f_{j^\pi}(E_i - E_{L_j}) E_i^3 \sum_{j} \sigma_{j^\pi}(E_i)$$

$$R = \frac{f(E_i - E_{L_1})}{f(E_i - E_{L_2})} = \frac{N_{L_1}(E_i)(E_i - E_{L_2})^3}{N_{L_2}(E_i)(E_i - E_{L_1})^3}$$

There is not enough strength to extract ratios and compare detailed features. We know that $(\alpha,\alpha')$ reaction is very selective…
Transitions with * previously reported by A. Jung et al., Nucl. Phys. A 584, 103 (1995).

What is the nature of high-lying states? Coulomb or nuclear excitations?
Dipole transition densities from Relativistic Quasiparticle Time Blocking Approximation (RQTBA) – E. Litvinova

Effect of Coulomb interaction on inelastic cross sections negligible.

Cross sections calculated with the Distorted Wave Born Approximation (DWBA) using DWUCK4.

Microscopic transition densities calculated using the RQTBA are used to perform the DWBA.
3-5 MeV strong isoscalar weak isovector.
5-8 MeV weak isoscalar strong isovector.
Characterization of States

3-5 MeV strong isoscalar  weak isovector.
5-8 MeV weak isoscalar  strong isovector.
4.55 MeV: n and p transition densities in phase inside and at nuclear surface. Isoscalar transition density has pattern typical with a node close to nuclear surface.

7.05 MeV: n and p transition densities in phase inside nucleus while surface region has contribution only from n, a behaviour typical of a pygmy dipole state.
Conclusion

- Broad experimental effort on $^{74}\text{Ge}$.
- Method to characterize feeding from the quasi-continuum to discrete states.
- $^{74}\text{Ge}(p,p')$ and $^{74}\text{Ge}(\alpha,\alpha')$ data.
- Up-bend is real.
- Pygmy resonance at $\sim 7$ MeV.
- What about $(\gamma,\gamma')$? Next Talk!
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